Urban Forestry & Urban Greening 40 (2019) 145–151

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Urban green infrastructure as a strategy of climate change mitigation. A case study in northern Spain☆

C. De la Sota[a,*], V.J. Ruffato-Ferreira[a,b], L. Ruiz-García[a], S. Alvarez[a]

[a] Innovation and Technology for Development Center, Universidad Politécnica de Madrid, Av. Complutense s/n, 28040, Madrid, Spain
[b] International Virtual Institute of Global Changes, Federal University of Rio de Janeiro, Pedro Calmon, 550, Cidade Universitária, Rio de Janeiro, 21941-901, Brazil

ARTICLE INFO

Keywords:
Carbon dioxide reduction
Sustainable urban development
Ecological footprint
Biocapacity

ABSTRACT

Sustainable development challenges are increasingly concentrated in urban areas. In the European Union (EU), cities are expanding their urban green infrastructure (UGI) to reduce the effects of climate change and enhance resilience and sustainability. However, there exist few articles showing local case studies in intermediate cities of Europe. The aim of this study is to analyse the climate change mitigation potential of a set of urban forests and agriculture actions implemented within the EU LIFE Program, in the northern Spain city of Lugo. First, the amount of CO_2 reduced by the UGI was calculated, also considering the emissions released from their implementation and management (I&M). In addition, the ecological balance was estimated, as an indicator to determine the sustainability of the UGI actions. Both biocapacity and quantity of emissions during I&M were found to be significantly different between the urban agriculture and urban forestry actions, showing that the type of UGI selected and its management has a great influence on the final carbon uptake. The global ecological balance was equal to 1.85 Global hectares, indicating that the evaluated UGI actions are effective at contributing to the climate change mitigation, in addition to other great co-benefits. Nonetheless, carbon uptake was 0.26 t C ha-1 per year, which is in the lower range compared to other cities in Europe. The quantification of benefits of this individual city experience is important to increase the attention of policies and management plans on UGI.

1. Introduction

In Europe, approximately 75% of the population currently lives in urban areas and urbanization is continuing to increase (Schröder et al., 2013). Cities offer many conveniences, as they concentrate much of the national economic activity, government, commerce and transportation and provide crucial links with rural areas, between cities and across international borders. Moreover, cities can also be models of environmental efficiency, because increased density and better management reduce the cost of service delivery, promote innovation and enable prosperity through economic development (The World Bank, 2010).

However, cities have become concentrated areas of production and consumption, radically altering global biophysical, economic, and social systems (Barles, 2010; Caputo et al., 2016; Rees, 1996). Although cities account for less than 2% of the earth's surface, they consume 78% of the world's energy and emit more than 70% global CO_2 emissions (habitat, 2016). This is because sustaining the well-being of urban populations requires a constant external input of energy, materials and information and the discharge of waste to the atmosphere, water and soils (Barles, 2010; Gandy, 2004; Rees, 1992; Wackernagel and Rees, 1996). Therefore, climate change is inextricably linked to urbanization (The World Bank, 2010).

At the same time, urban regions of the world are already facing the adverse effects of climate change (de Zeeuw and Drechsel, 2015; Field et al., 2014; Kumar et al., 2016; Lwasa et al., 2014; The World Bank, 2010), which are expected to worsen in the coming decades (Field et al., 2014). Climate change poses serious threats to urban infrastructure, quality of life and entire urban systems (The World Bank, 2010).

Due to all the above facts, it has been widely accepted that sustainable development challenges will be increasingly concentrated in cities (United Nations, 2017, United Nations, 2014), and the challenge in building resilient cities lies in how they are managed and developed (Ranjha, 2016). Cities are also centres of knowledge and innovation

☆ This article is part of a special issue entitled "Urban Green Infrastructure – Connecting People and Nature for Sustainable Cities" published at the journal Urban Forestry & Urban Greening 40C, 2019.

* Corresponding author.
E-mail addresses: candela.delasota@upm.es (C. De la Sota), veraruffato@ivig.coppe.ufrj.br (V.J. Ruffato-Ferreira), luis.ruiz@upm.es (L. Ruiz-García), sergio.alvarez@upm.es (S. Alvarez).

https://doi.org/10.1016/j.ufug.2018.09.004
Received 7 February 2018; Received in revised form 1 August 2018; Accepted 11 September 2018
Available online 15 September 2018
1618-8667/

(Ranjha, 2016), where an integrated approach that considers mitigation, adaptation, urban development and improvement of the city's resilience is being developed (The World Bank, 2010).

One of the major tools to reduce the effects of climate change and enhance urban resilience and sustainability is the development of urban green infrastructure (UGI) (de Zeeuw and Drechsel, 2015; Dubbeling, 2014; Field et al., 2014; Lennon and Scott, 2014; Lwasa et al., 2013; Meerow and Newell, 2017; Ranjha, 2016), which is described as an integrated network of natural and semi-natural areas and features, such as urban green spaces, greenways, parks, rain gardens, greenways, urban forestry, urban agriculture, green roofs and walls, etc..

UGI also provides a diverse set of social, ecological and economic benefits, as it has been reflected in the literature: improvement in air quality (Brantley et al., 2013; Freer-Smith et al., 2005; Setala et al., 2013); reduced noise pollution; production of food, wood and fuel (Dubbeling et al., 2009); water management (Ellis, 2012; Gill et al., 2007; Jacobson, 2011); reduced water pollution (Manning, 2008); carbon capture and storage (Davies et al., 2011; Dubbeling, 2014; Nowak et al., 2013; The World Bank, 2010; Velasco and Roth, 2010); reduced energy use in buildings (Cameron et al., 2012; Jaffal et al., 2012; Qin et al., 2012); reduced heat island effect (Manning, 2008); social benefits (inclusion, cohesion, more sustainable behaviour patterns) (Forsyth and Musacchio, 2005; Grimm et al., 2008; Peschardt et al., 2012; Sanz-Cobeña et al., 2017); human health and well-being (McPherson and Simpson, 2002; Nordh et al., 2009); ecological benefits (Constanza et al., 2018; Weber et al., 2006).

In the context of the European Union (EU), the development of an UGI is present in several national, regional and local planning, policy documents and strategies (Lafortezza et al., 2013) and it recognised as a fundamental tool in tackling climate change (EEA, 2010) and as a valuable approach for spatial planning. Good examples of it are the European Green Belt, the European Green Infrastructure Strategy or the Natural Water Retention Measures (NWRM) (de Zeeuw and Drechsel, 2015).

Carbon uptake and sequestration is one of the main indicators for measuring ecosystem service provision of UGI and the one that has important implications beyond the urban scale. Studies on carbon uptake provided by UGI are available for a number of cities in the world: in the USA, where most of the research in this field has been conducted to date (Churkina et al., 2010; Hutyra et al., 2010; Nowak et al., 2006; Nowak and Crane, 2002); in Asia (Jo, 2002; Zhao et al., 2010) in Australia (Brack, 2002) and in the EU (Chaparro and Terradas, 2009; Davies et al., 2011; Strohbach and Haase, 2012).

Nevertheless, there exist few peer-reviewed articles showing local case studies in Europe (Schröder et al., 2013), and this scarcity is bigger when talking about intermediate cities (from 20,000 to 500,000 inhabitants (Bellet and Llop, 1999)). As a wide variety of factors of the green infrastructure, such as age (Rowntree and Nowak, 1991), composition (Nowak and Crane, 2002), location (Zhao et al., 2010), distance from the urban core (Alberti and Hutyra, 2009), history (Brack, 2002; Nowak, 1993) or type of management (Lwasa et al., 2014; Nowak et al., 2002) influence CO_2 capture dynamics, transferring values between cities cannot always be appropriate (Strohbach and Haase, 2012). Moreover, CO_2 mitigation potential of UGI has been traditionally estimated without taking into account the emission of greenhouse gases (GHG) due to its implementation and maintenance (Nowak et al., 2002).

2. Objectives

The final objective of the research is to improve the quality and quantity of the urban green infrastructure initiatives in European intermediate cities. To this end, this paper analyses the climate change mitigation potential of a series of UGI interventions in Lugo, an intermediate city in northern Spain, within the framework of the EU LIFE Project called *Lugo + biodinámico*.

First, the amount of atmospheric $CO_{2\text{-eq}}$ reduced through direct carbon uptake by the new urban forests and agriculture is calculated, taking into account the emissions released from their implementation and management. Then, the ecological balance is estimated, as an indicator to determine the sustainability of the UGI actions implemented. It consists of the balance between the biocapacity of the new forestry plantations and urban agriculture and the ecological footprint of their implementation and management activities.

3. Methods

3.1. Case study framework

Lugo is a municipality located in north-western Spain, with a population of approximately 98,000 people and an overall density population of 295 inhabitants/km^2. Its climate is oceanic, with Mediterranean and Continental influences. The capital of the municipality, also called Lugo, is a city of 7.5 km^2, with approximately 0.5 km^2 of green areas, although important differences occur along the city. While the city core consists of a quite densely developed area with administrative and cultural facilities, few street trees and parks, in the surrounding areas, houses usually have private vegetated backyards and small allotment garden plots, although trees or public parks are also scarce. A short distance from the urbanized areas there are several large parks and a large riparian hardwood forest along the rivers Miño, Rato and Fervedoira.

According to recent estimates, the city of Lugo will have to face significant changes in climate trends and the resulting impacts. These include a generalized decrease in the average annual rainfall, an increase in the average monthly temperature and daily minimums and maximums, with the consequent decrease in the number of frost episodes (Morata, 2014).

It is in this context that the LIFE Project, a municipal proposal financed by the council of Lugo and the support of the EU through the LIFE program, came into existence. The LIFE program is the EU funding for the environment and climate actions. LIFE began in 1992 with the objective of contributing to the implementation, updating and development of EU environmental and climate policy and legislation, by co-financing projects with European added value.

The LIFE Project includes innovative actions to mitigate emissions and increase urban resilience, some of them focused on the creation of new urban green infrastructure: i) creation of a demonstration plot for dense native silviculture; ii) urban demonstration of wood chip biofuels production; iii) establishment of a demonstration chestnut grove to enhance biodiversity and as a resource for traditional products; iv) restoration of a Ribera forest; v) creation of a demonstration arboretum with native tree, bush and shrub species representative of Galician habitats and vi) establishment of urban agriculture in experimental land plots.

These actions have been implemented in the northeast of the city, in the vicinity of two industrial parks and an important shopping centre. This area is characterized by having a scattered urbanism, few green spaces, poor connection with the rest of the city and many large free areas, which present an opportunity to develop a new urban green infrastructure. Likewise, the proposed action area is located in the area of the "Green Belt" that surrounds the entire city, from the West to the Northwest, following the fluvial courses of the rivers Miño, Rato and Fervedoira.

3.2. Description of the urban green infrastructure actions under study

The UGI implementation actions of *Lugo + Biodinámico* project studied are divided into two types: urban forestry and urban agriculture. Urban agriculture is considered an integral part of the urban socio-economic and ecological system, which is strongly influenced by urban conditions, uses urban resources, produces for urban citizens and

Table 1
Characteristics of the Urban Green Infrastructure analysed.

Type of UGI* intervention	Action	Description	Area (ha)
Urban forestry	Forestry of native hardwoods	1,100 *Acer pseudoplatanus*, 1,100 *Quercus robur*, 1,100 *Prunus avium* and 1,100 *Fraxinus excelsior* planted for the production of quality timber. 300 m^3 of each species will be cut for clearings, and used for crushing wood. A final turn (after 60 years), of 300 m^3 of each species, for building timber.	4.5
	Energy crops	4,000 *Populus alba* and 5,000 *Myscanthus* planted. After 3, 6, 9 and 12 years, 10 ton (dry matter) will be cut for energy uses. At the end of 12 years, all trees will be cut for energy use and the area will remain free.	1
	Chestnut forest	280 feet of Galician varieties of chestnut grafted on hybrid patterns (7521, 2671, P042, P011, C004, C053)	3.9
	Arboretum	569 specimens of different shrub and tree species representative of Galician habitats. A complete list of species planted is presented in Table S1.	5
Urban agriculture	Urban agriculture	Vegetables well adapted to the agro climatic characteristics of Lugo and of great tradition in the area, such as cabbage, turnip, potato, lettuce, etc. Use of organic fertilization techniques according to the European regulation of organic agriculture.	0.4

* UGI: urban green infrastructure.

impacts the urban system (Mougeot, 2000). Besides that, urban forestry is defined as the “sum of all woody and associated vegetation in and around dense human settlements” (Konijnendijk et al., 2006; Miller, 1997). Table 1 describes the main characteristics of the UGI actions analysed in this study.

3.3. Calculation concepts and adaptations

The ecological footprint is an indicator of sustainability, designed in 1996 by Mathis Wackernagel and William Rees, which compares the resource demands of a given population with the regenerative capacity of the planet. In order to calculate this, the resources consumed by a given population or activity are determined, and the extension of ecologically productive area required to compensate for this impact is calculated, which is measured in units of global hectares (Gha) (Cervi and de Carvalho, 2010; Wackernagel and Rees, 1996).

In its initial conception, the ecological footprint is linked to a certain territory, since the main characters of the calculation are the inhabitants of the studied area, being its footprint compared to the ecologically productive surface of that area. However, new contributions have emerged applying the ecological footprint to other realities, such as corporations (Chambers and Lewis, 2001; Doménech, 2006; Lehni, 1999; Wiedmann et al., 2007). The analysis of the ecological footprint is flexible enough as to be applied in different fields, can be adapted to different scales (individual, neighbourhood, city, region, and country) and different activities (housing, mobility, food, etc.) (Muñiz et al., 2013). Diverse studies have used the ecological footprint to analyse the changes in the urban model (Moos et al., 2006; Muñiz et al., 2013). However, there are still few and recent studies that correlate the ecological footprint with the forms of urban development (Muñiz et al., 2013).

In this work, a conceptual adaptation of the methodologies for calculating the ecological footprint has been carried out to evaluate the impact of the changes provided by the LIFE Project. Firstly, GHG emissions derived from the implementation activities of the urban forest and agriculture (consumption of materials, transport, use of machinery, etc.) have been calculated and expressed in equivalent emissions of carbon. Secondly, the mass of $CO_{2\text{-eq}}$ was converted in global hectares of productive area, as is normally done in the case of the ecological footprint. Then, the ecological balance has been calculated to estimate if the productive hectares demanded by the activities to establish the urban gardens and forestry plantations are compensated by the productive capacity (or biocapacity) of new hectares of forest and gardens.

Biocapacity represents the “endowment” of ecologically productive territory that is locally available and it indicates the local ecosystem’s potential capacity to provide natural resources and services (Bagliani et al., 2008). If the biocapacity of the plantations is less than the ecological footprint of the activities, there will be an ecological deficit (negative ecological balance), and, therefore, a negative environmental impact of the project. On the other hand, if the productive capacity is greater than the footprint, the project will have a positive ecological balance and contribute to the mitigation of climate change.

3.3.1. $CO_{2\text{-eq}}$ emissions calculation and ecological footprint

The existent biomass before forestry plantations and urban agriculture implementation consisted of non-timber species (mainly herbaceous and shrub), which were cleared, crushed, and scattered throughout the land. Biomass related to non-timber plants is relatively ephemeral, as it decays and regenerates annually or every few years. Therefore, the decomposition emissions are offset by the absorptions due to regeneration, which means that the net general inventories of carbon are fairly stable in the long term. In this study, emissions from biomass decomposition have not be accounted, as they are very small compared to the others (IPCC, 2006).

Calculation of $CO_{2\text{-eq}}$ emissions derived from the implementation and management activities of urban forests and agriculture has been done using the Eq. (1).

$$Q \times EF = t\ CO_{2\text{-eq}} \tag{1}$$

Where: Q = Quantity of product (kg, L, etc.) and EF = Emission Factor (g $CO_{2\text{-eq}}$ J^{-1}, kg $CO_{2\text{-eq}}$ L^{-1}, etc.). Priority has been given to local emission factors, following the criteria established by Wackernagel and Rees, (1996). An inventory of all the components directly associated with the implementation actions of the plantations was done: machinery, transport, inputs (e.g. fertilizers) and water for irrigation. Table S2 summarizes the EF used for calculation and the source.

Subsequently, the $CO_{2\text{-eq}}$ emissions value has been converted into the Ecological Footprint. For this purpose, the amount of carbon present in an temperate ocean forest in Europe has been used: 200 tonnes of dry matter per hectare (IPCC, 2006). The amount of dry biomass has been then converted to amount of carbon, and this, in turn, to $CO_{2\text{-eq}}$, following the factors determined by the IPCC: 0.5 and 3.6, respectively (IPCC, 2006). Thus, the amount of t $CO_{2\text{-eq}}$ in 1 ha of temperate oceanic forest is 360 t $CO_{2\text{-eq}}$ ha^{-1}. With this factor, it is possible to estimate the equivalent area of forest (in ha) needed to compensate for emissions associated with implementation and management activities of urban gardens and forestry plantations. Finally, conversion to global hectares (Gha) was done with the conversion factor of 1.34, defined for forests by (Kitzes et al., 2008).

3.3.2. Calculation of $CO_{2\text{-eq}}$ absorption and biocapacity of new forest plantations and urban agriculture

Calculation of $CO_{2\text{-eq}}$ absorptions of the new forest plantations has been made using a calculation methodology developed by the Ministry of Agriculture, Food and Environment of Spain (MAPAMA, 2015). Calculation of $CO_{2\text{-eq}}$ absorptions of the new forest plantations has been made using a methodology developed by the Ministry of Agriculture, Food and Environment of Spain (MAPAMA, 2015), approved by the Intergovernmental Panel on Climate Change (IPCC). This methodology

takes into account carbon stocks variations in living biomass (both aerial and below-ground), based on the growth estimates of forest species in the Spanish territory (Table S3). Dry matter carbon fraction considered is the default value in the IPCC. According to this methodology, the calculation is based on the determination of the $CO_{2\text{-eq}}$ absorptions per specimen planted on a time horizon of 40 years (MAPAMA, 2015).

Under this scheme, two calculations have been applied, depending on the type of management carried out: (a) non-intensive management, when the objective of the plantation is not commercial; and (b) intensive management, when there is a clear-cutting management and high commercial value. In option a, $CO_{2\text{-eq}}$ absorbed is estimated at the end of the time horizon (40 years). In option b, $CO_{2\text{-eq}}$ absorbed is estimated at the end of the rotation period, which depends on the specific species. It should be noted that the same quantity of cut biomass is restored by planting new trees, so it is considered that after a period the same absorption rates will again be reached.

To estimate the $CO_{2\text{-eq}}$ uptaken by urban agriculture, a scientific study by Mota et al. (2011) was considered. This research estimated the annual rate of $CO_{2\text{-eq}}$ uptaken by different crop types considering both aerial and below-ground biomass. Based on Mota et al. (2011), we considered that urban agriculture capture 0.795 $tCO_{2\text{-eq}}$/ha per year (average across all crops included in the study), considering a time horizon of 40 years. Subsequently, total $CO_{2\text{-eq}}$ absorption values have been converted into bioproductive capacity, measured in global hectares (Gha), to allow comparison with the Ecological Footprint of the project and estimate its Ecological Balance.

3.3.3. Ecological balance estimation

The Ecological Balance consists of the balance between the ecological footprint and the biocapacity of the site, process, individual, or as in our case, of the implementation of forestry plantations and urban agriculture (Cervi and de Carvalho, 2010).

4. Results and discussion

4.1. $CO_{2\text{-eq}}$ emissions from forestry plantations and urban agriculture

Fig. 1 shows the quantity of $CO_{2\text{-eq}}$ emissions released during implementation and management activities of UGI actions under study in a time horizon of 40 years. Total emissions released account for 22.36 $tCO_{2\text{-eq}}$, with 58% derived from the use of machinery (13 $tCO_{2\text{-eq}}$). During planting activities, the use of tractors is important for soil tilling and irrigation. The use of machinery implies great fuel consumption, mainly gasoil, which emits to the atmosphere a great amount of GHG. The actions of forestry of native hardwood, chestnut forest and the arboretum have the highest $CO_{2\text{-eq}}$ emissions of all the UGI actions evaluated.

The amount of fuel consumption due to the transportation of plants and other materials is also important. This represents the 22% of total emissions (5 $tCO_{2\text{-eq}}$). Emissions from transport are also significant because, like machinery, the vehicles used in the proyect consume fossil fuels. In a third level, the 15% of total emissions come from the use of inputs, mainly due to the use of fertilizers in urban agriculture.

Compared with other activities, the use of irrigation water is the least contributing to $CO_{2\text{-eq}}$ emissions (1 $tCO_{2\text{-eq}}$ and 5% of total emissions). This is due to the fact that Lugo has a rainy weather and planting actions were carried out during the beginning of the rainy season. Almost 100% of irrigation emissions correspond to the urban agriculture actions, since these plants do need constant irrigation, unlike trees, for which only irrigation is estimated during the process of planting and growing in the first year.

Indeed, substantial differences are observed in Fig. 1 regarding the contribution of emissions from urban agriculture and urban forestry actions. While in urban forestry, emissions released mainly come from the use machinery and transport, for the urban agriculture, most emissions are related to inputs, i.e. fertilizers and irrigation.

Therefore, the implementation and maintenance of UGI are also sources of GHG emissions. And the quantity of emissions released are highly dependent on management aspects, such as the quantity and type of chemical fertilizers and pesticides, type of machinery used and their energy efficiency and GHG emissions, energy costs of setting up the system, etc.

In order to maximize CO_2 sequestration, fossil fuel consumption related to management activities of the LIFE Project should be minimized and biomass used, where possible, as an alternative renewable energy source (Chaparro and Terradas, 2009). On the other hand, the use of chemical fertilizers should be regulated with caution, since this operation increase the GHG emissions (IPCC, 2006). As an alternative, compost or plant material obtained from pruning can be used, as it helps to the fixation of carbon in the soil during its decomposition (Brady and Weil, 2010).

Estimation uncertainty arises any time greenhouse gas emissions are quantified (IPCC, 2001). Total uncertainty has been calculated

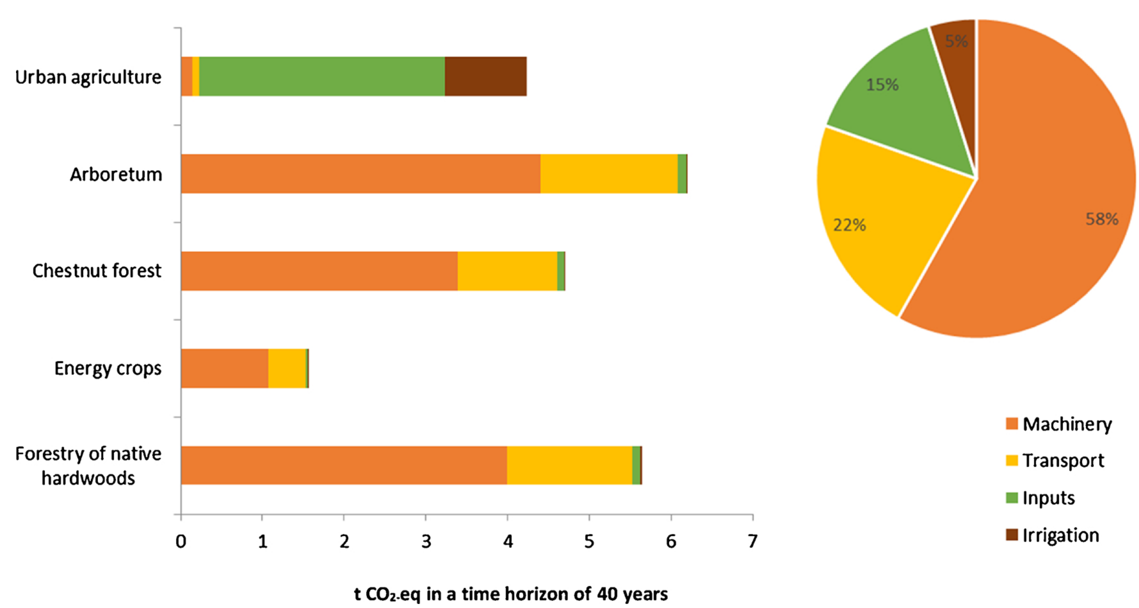

Fig. 1. $CO_{2\text{-eq}}$ emissions per urban green infrastructure action.

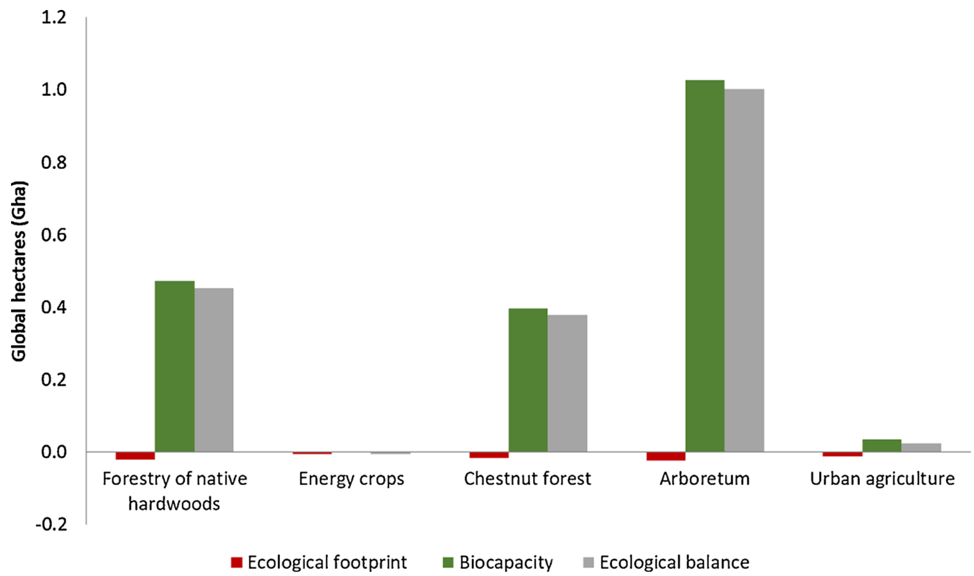

Fig. 2. Ecological footprint, biocapacity and ecological balance per urban green infrastructure action.

combining uncertainty associated to the activity data (ranging between 5 and 20% for the different implementation and management activities) and the uncertainty in emission factors (ranging between 1 and 5%). Using the error propagation equation (IPCC, 2001), an aggregate uncertainty of 4.99% has been reached.

4.2. Ecological balance of forestry plantation and urban agriculture actions

Red colour bars in Fig. 2 represent the ecological footprint from implementation and management of the LIFE Project actions and the green colour bars represents the biocapacity of the new UGI, both expressed in Gha. Fig. 2 shows that four of the five evaluated actions had a positive ecological balance (grey bars), with the exception of Energy crops action, which is characterized by a nearly breakeven ecological balance. This is because in the energy crops action it is considered that there will be no net CO_2 uptake, since all the CO_2 absorbed by the process of photosynthesis during the life of the forest species will be emitted during their burning for energy production.

As expected, high differences are also observed between the different types of UGI (forestry and urban agriculture). Urban agriculture biocapacity is not very different from herbaceous vegetation land cover, which is much smaller when compared with areas of tree cover, such as the chestnut, arboretum or hardwood forests. Tree areas are typically much more effective as agriculture in a storing carbon per hectare basis. This is not only because they have a higher aerial and below-ground biomass, but also because agricultural plants are periodically cut and harvested. In the same way, the reforestation of forests or natural areas is much more effective for storing carbon than parks, tree cultivation or other urbans green areas. This statement is also supported by the results of Calfapietra et al., (2015) and Martin et al., (2012).

The total ecological footprint of the implementation and management of the urban agriculture and forestry plantations is 0.088 Gha and the estimated total biocapacity is 1.93 Gha. In this way, the global ecological balance is positive, and equal to 1.85 Gha. This indicates that the evaluated UGI actions are effective at offsetting annual CO_2 emissions and therefore, they effectively contribute to the climate change mitigation.

When considering all the actions of Lugo + Biodinámico project, average value of C uptaken per ha is 0.26 t C ha^{-1} per year. This value is in the lower range compared to the results estimated in other case studies, like Barcelona (Spain) (range:3-33.3 t C ha^{-1}) (Chaparro and Terradas, 2009), Oakland (USA), (0.5–27.9 t C ha^{-1}) (Nowak, 1993), or Leicester (UK) (1.4–288.6 t C ha^{-1}) (Dubbeling, 2014). As explained before, the differences may be due to age (Rowntree and Nowak, 1991), composition (Nowak et al., 2002), location (Zhao et al., 2010) or type of management (Lwasa et al., 2014; Nowak et al., 2002). Moreover, the direct comparison between different studies is somewhat problematic because these studies use different calculation methodologies and consider very different types of UGI.

As can be seen, the type of green infrastructure selected in the planning of a city has a great influence on the carbon uptake capacity. The implementation of urban forests and the restoration of natural areas are much more effective in achieving these goals, in addition to bringing greater co-benefits.

The installation of linear parks on river banks, recovering the natural riverside vegetation, can be a great strategy (Alvarez and Rubio, 2015). The installation of parks and squares are also strategic. On the other hand, the carbon uptake is not the only factor to be considered in urban planning for a sustainable city. Social, psychological, and quality of life factors are other benefits that must be taken into account in planning.

4.3. Co-benefits of urban forestry and agriculture actions

The benefits of UGI go beyond mitigating carbon emissions. Even though there is an urgent need to be concerned with the effects of eminent climate change, we cannot forget the co-benefits generated by these green areas.

Trees in an urban environment influence the local climate and consequently the thermal comfort (Mihelcic and Zimmerman, 2012; Souch, 1993). Trees also remove the pollution present in the air through its leaf surface (Nowak and Dwyer, 2007; Smith, 1990). In addition, vegetation has the potential to block sound sources, reducing the amount of noise perceived by individuals (Anderson et al., 1984; Nowak and Dwyer, 2007; Robinette, 1972).

The reduction of stress and the improvement of the physical health of the population of the cities have been associated with the presence of urban trees in diverse environments (Nowak and Dwyer, 2007). When viewed from an office window, the vegetation can provide a number of psychological benefits that affect the productivity and well-being of the person (Kaplan, 1993; Nowak and Dwyer, 2007). In a school, the trees can improve the behaviour and children's learning (Taylor et al., 2001). Driving by wooded environments reduces stress commonly generated by urban traffic (Mihelcic and Zimmerman, 2012). It is also estimated that in wooded streets there is an increase in trade incomes, being an important competitive factor for shopkeepers (Mihelcic and

Zimmerman, 2012).

5. Conclusions

This article presents the analysis of the ecological footprint and the biocapacity of a set of urban green infrastructure actions co-financed by the European LIFE program in the city of Lugo, a European intermediate city in northern Spain. This is particularly interesting because, even though more and more cities are incorporating UGI into the urban development frameworks to increase their resilience to climate change, sometimes this is complicated, due to landscape competition with urbanization, commercial activities or industry.

It is important to improve the planning and management plans about UGI, in order to quantify and evaluate their benefits, based on individual city experiences. Moreover, understanding and quantifying these benefits can raise citizen awareness of the value of their green public resources, as well as provide a basis for maximizing their benefits.

Results of this study showed a positive global ecological balance of the UGI actions, indicating a positive environmental effect, in addition to a wide variety of co-benefits. However, the carbon uptake per hectare of UGI is still small when compared with other urban green infrastructure actions in other European cities. This shows that despite the emissions from the implementation of this type of infrastructure, the absorptive capacity of the areas created is more than sufficient to mitigate this impact, and may even mitigate other impacts resulting from other interventions linked to the development of the city.

The other co-benefits generated by the installation of the green infrastructure should be taken in to account for the development of a new city model. The quantification of these benefits would provide useful data to the public administrations and decision makers, not only in northern Spain, but also in other European metropolitan territories. In this way, they can offer new alternative ways of acting in the climate change scenario and their consequences in urban environments. Further studies monitoring the environmental impacts of the actions should use more holistic indicators and methods of analysis to have a more comprehensive picture.

Acknowledgements

The authors wish to thanks the city council of Lugo and the LIFE program, through the Project LIFE 14 CCA/ES/00489, for the financial support provided to carry out the implementation of the urban green infrastructure, analysed in this article. The authors also acknowledge the University of Santiago de Compostela for the technical support.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2018.09.004.

References

Alberti, M., Hutyra, L., 2009. Detecting carbon signatures of development patterns across a gradient of urbanization: linking observations, models, and scenarios. 5th Urban Research Symposium on Cities and Climate Change: Responding to an Urgent Agenda.

Alvarez, S., Rubio, A., 2015. Carbon footprint in Green Public Procurement: a case study in the services sector. J. Clean. Prod. 93, 159–166. https://doi.org/10.1016/j.jclepro.2015.01.048.

Anderson, L.M., Mulligan, B.E., Goodman, L.S., 1984. Effects of vegetation on human response to sound. J. Arboric. 10, 45–49.

Bagliani, M., Galli, A., Niccolucci, V., Marchettini, N., 2008. Ecological footprint analysis applied to a sub-national area: the case of the Province of Siena (Italy). J. Environ. Manag. 86, 354–364. https://doi.org/10.1016/j.jenvman.2006.04.015.

Barles, S., 2010. Society, energy and materials: the contribution of urban metabolism studies to sustainable urban development issues. J. Environ. Plan. Manag. 53, 439–455. https://doi.org/10.1080/09640561003703772.

Bellet, C., Llop, J., 1999. Intermediate Cities and World Urbanisation. Ajuntament de Lleida, UNESCO, UIA, Ministerio de Asuntos Exteriores. ed., Lleida, Spain.

Brack, C., 2002. Pollution mitigation and carbon sequestration by an urban forest. Environ. Pollut. 116, 195–200.

Brady, N., Weil, R., 2010. Elements of the Nature and Properties of Soils. Pearson Prentice, Hall, NJ, USA.

Brantley, H., Hagler, G., Deshmukh, P., Baldauf, R., 2013. Field assessment of the effects of roadside vegetation on near-road black carbon and particulate matter. Sci. Total Environ. 468–469, 120–129.

Calfapietra, C., Barbati, A., Perugini, L., Ferrari, B., Guidolotti, G., Quatrini, A., Corona, P., 2015. Carbon mitigation potential of different forest ecosystems under climate change and various managements in italy. Ecosyst. Health Sustain. 1, 1–9. https://doi.org/10.1890/EHS15-0023.

Cameron, R., Blanusa, T., Taylor, J., Salisbury, A., Halstead, A., Henricot, B., Thompson, K., 2012. The domestic garden e its contribution to urban green infrastructure. Urban For. Urban Green. 11, 129–137.

Caputo, P., Pasetti, G., Bonomi, M., 2016. Urban metabolism analysis as a support to drive metropolitan development. Procedia Eng. 161, 1588–1595. https://doi.org/10.1016/j.proeng.2016.08.631.

Cervi, J.L., de Carvalho, P.G.M., 2010. A pegada ecológica do município do Rio de Janeiro. Revibec Rev. Iberoam. Econ. Ecológica 15, 15–29.

Chambers, N., Lewis, K., 2001. Ecological Footprint Analysis: Owards a Sustainability Indicador for Bussiness. (No. 65). Association of Chartered Certified Accounts, London.

Chaparro, L., Terradas, J., 2009. Ecological Services of Urban Forest in Barcelona. Ajuntament de Barcelona: Àrea de Medi Ambient Institut Municipal de Parcs i Jardins.

Churkina, G., Brown, D.G., Keoleian, G., 2010. Carbon stored in human settlements: the conterminous United States. Global Change Biol. 16, 135–143.

Constanza, R., d'arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., Van den Belt, n.d. The value of the world's ecosystem services and natural capital. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Davies, Z.G., Edmondson, J.L., Heinemeyer, A., Leake, J.R., Gaston, K.J., 2011. Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale: Urban above-ground carbon storage. J. Appl. Ecol. 48, 1125–1134. https://doi.org/10.1111/j.1365-2664.2011.02021.x.

de Zeeuw, H., Drechsel, P., 2015. Cities and Agriculture: Developing Resilient Urban Food Systems. Earthscan Food and Agriculture. Routledge.

Doménech, J.L., 2006. Guía metodológica para el cálculo de la huella ecológica corporativa.

Dubbeling, M., 2014. Report on the Most Relevant Potential Impacts of Urban and Peri-Urban Agriculture and Forestry on Climate Change Adaptation, Mitigation and Other Co-Developmental Benefits (No. 1.1.), Project IFQ1-1036 Monitoring Impacts of Urban and Peri-Urban Agriculture and Forestry on Climate Change. Resource Centres on Urban Agriculture and Food Security.

Dubbeling, M., Campbell, M.C., Hoekstra, F., van Veenhuizen, R., 2009. Building resilient cities. Urban Agric. Mag. 22, 3–11.

EEA, 2010. The European Environment. State and Outlook 2010. European Environment Agency, Copenhagen, Denmark.

Ellis, J., 2012. Sustainable surface water management and green infrastructure in UK urban catchment planning. J. Environ. Plan. Manag. 56, 24–41.

Field, C.B., Barros, V.R., Mach, K., Mastrandrea, M., 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Forsyth, A., Musacchio, L.R., 2005. Designing Small Parks: A Manual for Addressing Social and Ecological Concerns.

Freer-Smith, P., Beckett, K., Taylor, G., 2005. Deposition velocities to Sorbus Aria, Acer Campestre, Populus Deltoides X Trichocarpa 'Beaupre', Pinus Nigra and X Cupressocyparis Leylandii for coarse, fine and ultra-fine particles in the urban environment. Environ. Pollut. 133, 157–167.

Gandy, M., 2004. Rethinking urban metabolism: water, space and the modern city. City 8, 363–379. https://doi.org/10.1080/1360481042000313509.

Gill, S., Handley, J., Ennos, A., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environ. 33, 115–133.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., Briggs, J.M., 2008. Global change and the ecology of cities. Science 319, 756–760.

habitat, U.N., 2016. The World Cities Report: Urbanization and Development (No. HS/038/16E). United Nations, 2017. New Urban Agenda, Quito, Ecuador.

Hutyra, L., Byungman, Y., Alberti, M., 2010. Terrestrial carbon stocks across a gradient of urbanization: a study of the Seattle, WA region. Global Change Biol. 17, 783–797.

IPCC, 2001. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. National Greenhouse Gas Inventories Programme, IGES, Japan.

Jacobson, C.R., 2011. Identification and quantification of the hydrological impacts of imperviousness in urban catchments: a review. J. Environ. Manag. 92, 1438–1448.

Jaffal, I., Ouldboukhitine, S., Belarbi, R., 2012. A comprehensive study of the impact of green roofs on building energy performance. Renew. Energy 43, 157–164.

Jo, H., 2002. Impacts of urban greenspace on offsetting carbon emissions for middle Korea. J. Environ. Manag. 64, 115–126. https://doi.org/10.1006/jema.2001.0491.

Kaplan, R., 1993. Urban Forestry and the Workplace. (Technical Report No. NC-163). USA Forest Service, Chicago.

Kitzes, J., Galli, A., Rizk, S.M., Reed, A., Wackernagel, M., 2008. Guidebook to the National Footprint Accounts, 2008 Edition. .

Konijnendijk, C.C., Ricard, R.M., Kenney, A., Randrup, T., 2006. Defining urban forestry – a comparative perspective of North America and Europe. Urban For. Urban Green. 4,

93–103.
Kumar, P., Geneletti, D., Nagendra, H., 2016. Spatial assessment of climate change vulnerability at city scale: a study in Bangalore, India. Land Use Policy 58, 514–532. https://doi.org/10.1016/j.landusepol.2016.08.018.
Lafortezza, R., Davies, C., Sanesi, G., Konijnendijk, C., 2013. Green infrastructure as a tool to support spatial planning in European urban regions. IForest – Biogeosci. For. 6, 102–108. https://doi.org/10.3832/ifor0723-006.
Lehni, M., 1999. El medio ambiente como factor clave de competitividad. Ecoeficiencia. Eco-Eficiencia, Los Negocios En El Próximo Milenio. Fundación Entorno, Madrid, pp. 23–28.
Lennon, M., Scott, M., 2014. Delivering ecosystems services via spatial planning: reviewing the possibilities and implications of a green infrastructure approach. Town Plan. Archit. 85. https://doi.org/10.3828/tpr.2014.35.
Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J., Griffith, C., 2013. Cities and agriculture: developing resilient urban food systems. Urban Clim. 7, 92–106.
Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J., Griffith, C., 2014. Urban and peri-urban agriculture and forestry: transcending poverty alleviation to climate change mitigation and adaptation. Urban Clim. 7, 92–106. https://doi.org/10.1016/j.uclim.2013.10.007.
Manning, W., 2008. Plants in urban ecosystems: essential role of urban forests in urban metabolism and succession toward sustainability. Int. J. Sustain. Dev. World Ecol. 15, 362–370. https://doi.org/10.3843/SusDev.15.4:12.
MAPAMA, 2015. Guía para la estimación de absorciones de dióxido de carbono.
Martin, N.A., Chappelka, A.H., Loewenstein, E.F., Keever, G.J., 2012. Comparison of carbon storage, carbon sequestration, and air pollution removal by protected and maintained urban forests in Alabama, USA. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 8, 265–272. https://doi.org/10.1080/21513732.2012.712550.
McPherson, E.G., Simpson, J.R., 2002. A comparison of municipal forest benefits and costs in Modesto and Santa monica, California, USA. Urban For. Urban Green. 1, 61–74.
Meerow, S., Newell, J.P., 2017. Spatial planning for multifunctional green infrastructure: growing resilience in detroit. Landsc. Urban Plan. 159, 62–75. https://doi.org/10.1016/j.landurbplan.2016.10.005.
Mihelcic, J.R., Zimmerman, J.B., 2012. Engenharia Ambiental: Fundamentos. Sustentabilidade e Projeto, Río de Janeiro.
Miller, R.W., 1997. Urban Forestry: Planning and Managing Urban Greenspaces. Prentice Hall, New Jersey.
Moos, M., Whitfield, J., Johnson, L.C., Andrey, J., 2006. Does design matter? The ecological footprint as a planning tool at the local level. J. Urban Des. 11, 195–224. https://doi.org/10.1080/13574800600644381.
Morata, A., 2014. Guía de escenarios regionalizados de cambio climático sobre España a partir de los resultados del IPCC-AR4. Ministerio de Agricultura, Alimentación y Medio Ambiente. Agencia Estatal de Meteorología, Madrid.
Mota, C., Alcaraz-López, C., Iglesias, M., Martínez-Ballesta, M.C., Carvajal, M., 2011. Absorción de CO2 por los cultivos más representativos de la Región de Murcia. Hortic. Glob. 58–63.
Mougeot, L.J.A., 2000. Urban agriculture: definition, presence, potentials and risks. Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda. DSE, Feldafing, Germany, pp. 99–117.
Muñiz, I., Calatayud, D., Dobaño, R., 2013. The compensation hypothesis in Barcelona measured through the ecological footprint of mobility and housing. Landsc. Urban Plan. 113, 113–119. https://doi.org/10.1016/j.landurbplan.2013.02.004.
Nordh, H., Hartig, T., Hagerhall, C.M., Fry, G., 2009. Components of small urban parks that predict the possibility for restoration. Urban For. Urban Green. 8, 225–235.
Nowak, D.J., 1993. Atmospheric carbon reduction by Urban trees. J. Environ. Manag. 37, 207–217.
Nowak, D.J., Crane, D.E., 2002. Carbon storage and sequestration by urban trees in the USA. Environ. Pollut. 116, 381–389.
Nowak, D.J., Dwyer, J.F., 2007. Understanding the Benefits and Costs of Urban Forest Ecosystems, in: Urban and Community Forestry in the Northeast. Springer, Netherlands, pp. 25–46.
Nowak, D.J., Stevens, J.C., Sisinni, S.M., Luley, C.J., 2002. Effects of Urban Tree Management and Species Selection on Atmospheric Carbon Dioxide.
Nowak, D.J., Crane, D.E., Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. Urban For. Urban Green. 4, 115–123. https://doi.org/10.1016/j.ufug.2006.01.007.
Nowak, D.J., Greenfield, E.J., Hoehn, R.E., Lapoint, E., 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environ. Pollut. 178, 229–236. https://doi.org/10.1016/j.envpol.2013.03.019.
Peschardt, K., Schipperijn, J., Stigsdotter, 2012. Use of small public urban green spaces (SPUGS). Urban For. Urban Green. 11, 235–244.
Qin, X., Wu, X., Chiew, Y.M., Li, Y., 2012. A green roof test bed for stormwater management and reduction of urban heat island effect in Singapore. Br. J. Environ. Clim. Change 2, 410–420.
Ranjha, S., 2016. Green Infrastructure_Planning for Sustainable and Resilient Urban Environment.
Rees, W.E., 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environ. Urban 4, 121–130. https://doi.org/10.1177/095624789200400212.
Rees, W.E., 1996. Revisiting carrying capacity: area-based indicators of sustainability. Popul. Environ. 17, 195–215.
Robinette, G.O., 1972. Plants, People, and Environmental Quality: A Study of Plants and Their Environmental Functions. U. S. Department of Interior, National Park Service, Washington, DC, USA.
Rowntree, R.A., Nowak, D.J., 1991. Quantifying the role of urban forests in removing atmospheric carbon dioxide. J. Arboric. 17, 269–275.
Sanz-Cobeña, A., Puigdueta-Bartolomé, I., Larruscain, Á., Borrella, I., Álvarez, S., Cruz, J.L., Pereira, D., Mazorra, J., Moreno, J., Iglesias, A., 2017. Los huertos urbanos como herramienta de trasformación socio-agroalimentaria y medida de mitigación de GEI: el caso de Madrid. Presented at the V Workshop REMEDIA.
Schröder, C., Mancosu, E., Roerink, G.J., 2013. Methodology Proposal for Estimation of Carbon Storage in Urban Green Areas. European Environment Agency.
Setala, H., Viipola, V., Rantalainen, A.L., Pennanen, A., Yli-Pelkonen, V., 2013. Does urban vegetation mitigate air pollution in northern conditions? Environ. Pollut. 183, 104–112.
Smith, W.H., 1990. Air Pollution and Forests. Interactions between Air Contaminants and Forest Ecosystems. Springer New York, New York.
Souch, C.A., 1993. The effect of trees on summertime below canopy urban climates: a case study, Bloomington, Indiana. J. Arboric. 19, 303–312.
Strohbach, M.W., Haase, D., 2012. Above-ground carbon storage by urban trees in Leipzig, Germany: analysis of patterns in a European city. Landsc. Urban Plan. 104, 95–104. https://doi.org/10.1016/j.landurbplan.2011.10.001.
Taylor, A.F., Kuo, F.E., Sullivan, W.C., 2001. Coping with add: the surprising connection to green play settings. Environ. Behav. 33, 54–77.
The World Bank, 2010. Cities and Climate Change. An Urgent Agenda. (Knowledge Papers No. 10), Urban Development Series. The World Bank.
United Nations, 2014. World Urbanization Prospects: The 2014 Revision: Highlights.
Velasco, E., Roth, M., 2010. Cities as net sources of CO2: review of atmospheric CO2 exchange in urban environments measured by Eddy covariance technique. Geogr. Compass 4, 1238–1259.
Wackernagel, M., Rees, W., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. Canada. .
Weber, T., Sloan, A., Wolf, J., 2006. Maryland's green infrastructure assessment: development of a comprehensive approach to land conservation. Landsc. Urban Plan. 77, 91–110.
Wiedmann, T., Barret, J., Lenzen, M., 2007. Companies on the scale: comparing and benchmarking the footprints of businesses. Presented at the International Ecological Footprint Conference 1–20.
Zhao, M., Kong, Z.H., Escobedo, F.J., Gao, J., 2010. Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. J. Environ. Manag. 91, 807–813.